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Urban air pollution, climate change and wildfires: The case study of an extended forest fire episode in northern Italy favoured by drought and warm weather conditions

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Abstract

The aim of the paper is to describe the spread forest fire event occurred in the Italian Alps in 2017 under extremely drought conditions. In the study the root causes of wildfires and their direct relapses to the air quality of the Western Po valley and the urban centre of Torino have been assessed by means of air pollution measurements (focused to particulate matter with reference samplers and optical particle counters OPCs), meteorological indicators and additional public data. Results show a good correlation among different urban sites and instrument technologies. Concentration data, compared with environmental conditions and historical values describe the clear impact of fires on both local and regional air quality. Indeed, the deferred impact of wildfires on the local wood biomass energy supply chain is briefly outlined.

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Keywords: Air quality; Biomass; Climate change; Forest fires; Particulate matter; Wildfires

1. Introduction

Air pollution is one of the main health risk factors in the world, accounting for more than 7 million life-losses annually [1], half of them related to urban air pollution [2]. Among air pollutant emissions, wildfires (i.e. forest fires) could represents a weighty source as demonstrated by the well-studied cases in South Europe, Mediterranean countries and California [3–6]. Therefore, beyond the health and safety concerns, forest fires are responsible of the depletion of biomass as the source of virtuous local bioenergy systems as well as the fragmentation of ecosystems, the loss of biodiversity and CO_2 capture, the degradation of soils and the instability of mountain slopes [7–9].

The Po valley mega-city region, occupying most of the northern part of Italy, is one of the most air-polluted European territories [10]. In fact, urban and regional continuous emissions combined with meteorological and

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morphological characteristics of the area, favour the persistence of pollutants and the frequent excess of normative air quality thresholds in most of its extension, particularly during wintertime [11]. In such scenario, rising concern for the occurrence of acute emissions by the increase of fires' — related to the intensification of extreme events such as the reduction of precipitations observed in recent warm summers — is reported [4,12–15].

In this paper, which is part of wider research developed by the authors [16–18], a critical event occurred in Autumn 2017 in the Western part of such region is described by analysing the main root causes of fires and their direct impact to the air quality (focusing to particulate matter, PM) of the metropolitan area of Torino (i.e. Turin) as well as a brief outline of the deferred impact on the local short wood biomass supply chain.

2. Event description

In October 2017 the drought which characterised the summer over most of the peninsula endured in the North-West of Italy. Led by positive surface pressure anomalies due to anticyclone persistence in the South-West of Europe, almost the entire extension of Piemonte (i.e. Piedmont) did not receive any rainfall. This event represented an exceptionally rare condition for one of the rainiest months in Northern Italy. Indeed, Torino's precipitations data series – started in 1802 – found its lowest October value in 2017, comparable only with the extreme drought 1921 [19]. Considering the interval July 1st–October 31st, only 101 mm of rain was measured, the third driest record observed after 1832 and 1871. Moreover, with a monthly-averaged temperature of 16.2 °C (+2.1 °C above the 1981–2010 average), Torino experienced its 4th warmest October since 1753, preceded only by the recent 2001, 2006 and 2014 cases. Temperatures combined with rainfalls and compared to 1832 and 1871, which had temperature 2–2.5 °C cooler, depict a spread and consistent ground evaporation process.

The significant soil dryness favoured the spread of several forest fires in the Alps mountain range in the second half of October 2017 (Fig. 1). Wildfires occurred into many Piemonte valleys (Stura, Varaita, Chisone, Susa, Orco and Chiusella) and in the territories of Cumiana and Cantalupa (geo-data available at the Copernicus Emergency Management Service website [20]). The wide-distribution and severity of fires were boosted locally by: strong gusts of Foehn on 22nd, 23rd, 27th and 29th of October; absence of snow (favouring the vertical distribution of fires); renaturation of cultured lands (i.e. excess of dry biomass); human factors (i.e. intentional and unintentional fires ignition).

The vast wildfires that begin in the Susa's valley in the late morning of October 22nd had spanned to more than a thousand metres of altitude in less than three hours. In following days, wildfires expanded westward to the Site of Community Importance "Orrido di Foresto" and to southern side part of Rocciamelone mountain. The Foehn gusts of October 27th led the fire to a vast pinewood forest where it developed rapidly into uncontrolled fireballs devastating woodlands and pasture areas between 700 and 2800 m of altitude. At the end of the phenomena, with the progressive reduction to local residual fires on October 31st and November 1st, preliminary estimates counted over 62 km^2 of forest losses representing the worst wildfires array of last 50 years in Piemonte. Most other extended episodes recorded in the past were concentrated in the dryer months of February and March, before widespread rainfall in spring. Excluding ephemeral Foehn episodes that have reached the Po valley, the stable atmosphere trapped increasing amounts of urban air pollutants at low altitudes. Intense smoke and fumigation led to un-breathable air in the valleys and nearer flat zones while, in the morning of October 27th, smoke olfactory and visual perception were reported in the city centre of Torino (45 km leeward from the largest fire of Susa's valley). For the same day, the public air pollution monitoring network, managed by Piemonte's Regional Agency for the Environment (ARPA), recorded the highest PM_{10} daily value (354 $\mu g/m^3$ at Beinasco) for the whole regional database, started in 2000 [21]. Along the event PM_x values over 150 $\mu g/m^3$ were reported by many urban, suburban and rural stations at different altitudes as Torino (250 m a.s.l.), Susa (500 m a.s.l.) and Ceresole Reale (1600 m a.s.l.) [22].

3. Air pollution assessment

Two measurement-sites for the assessment of air pollutants throughout fire development were established. The first, called Urban Measuring Site (UMS) was located at the Politecnico di Torino main campus, in a densely urbanised district and not directly exposed to specific emissive sources (i.e. traffic, industrial). The measurement chain consists of an environmental airborne particulate low-volume reference sampler supported by real-time optical particle counters (OPCs) for the esteem of PM_{10}, $PM_{2.5}$ and PM_1 concentrations over shorter time-scales. In accordance with other published researches [23], during the event an additional parametrical measurement had been

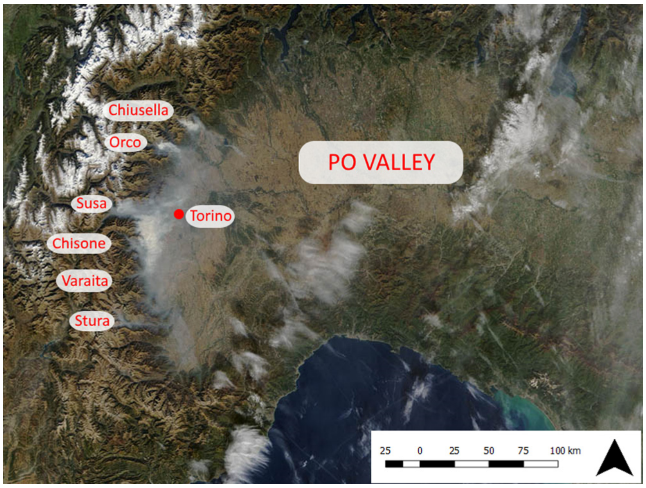

Fig. 1. Satellite image of wildfires, 25th October 2017 (basemap: Nasa Worldview).

developed at the area involved by forest fires (called Near Source Measuring Site — NSMS). A PM_{10} low-volume reference sampler had been placed in a rural context at 450 m a.s.l. leeward from the front of wildfire.

Documentation released by local public authorities throughout the event had been collected and examined. Concentrations from the ARPA's public air pollution monitoring system had been analysed and compared with $PM_{2.5}$ daily concentrations obtained by the reference sampler at UMS. The comparison, supported by meteorological indicators, takes into account the different context and location of each measuring site and the adopted reference technologies. Three stations in the urban area of Torino were considered in detail: "Torino-Lingotto" corresponds to an urban background station (i.e. not directly affected by a prevailing emissive source like traffic) measuring $PM_{2.5}$ by low-volume reference sampler since 2005; "Torino-Rebaudengo" is a urban traffic station measuring $PM_{2.5}$ by a beta-attenuation reference sampler starting from the end of 2013 and reporting particle counter data from 2011; "Torino-Rubino" is an urban background station which measures $PM_{2.5}$ at hourly time scale using a beta-attenuation sampler from 2013.

4. Results

At the NSMS, before the arrival of Foehn gusts of October 27th, a peak of 334 μg/m^3 had been recorded (distance of 3–5 km from fires). In correspondence with such measurement, heavy smoke at the ground affected an extended part of Susa's valley and neighbouring territories. At wind calm, after Foehn, 24-h mean concentration of 46 μg/m^3 were recorded (October 28th). Reinforcements of wind gusts led to 86 μg/m^3 at 7–8 km down-wind from fires (October 29th). During a second wind calm interval, 37 μg/m^3 were sampled (October 30th). At the end of the fire crisis, between October 31st and November 2nd, average concentrations were estimated to be 69 μg/m^3. Dry conditions persisted throughout the entire campaign.

At the UMS, the sampled $PM_{2.5}$ daily values have been combined with the $PM_{2.5}$ hourly mean elaborated from OPCs raw data (Fig. 2). High correlation ($R^2 = 0.97$–0.99) over 1-h mean values of PM_{10}, $PM_{2.5}$ and PM_1 among OPCs is found. Minor correlation ($R^2 = 0.55$) between low-volume and OPCs is observed. A clear intensification of urban concentrations during fires' evolution have been recorded by all instruments.

The trend is confirmed by the comparison of UMS data with Lingotto (low-volume), Rebaudengo (beta-attenuation), Rebaudengo (particle counter) and Rubino (beta-attenuation) data (Fig. 1). Differences in location and instrument typology among datasets are described graphically using line patterns (for technologies) and colours (for sites). For the observed period, Torino's daily measurements ranged between 16 μg/m^3 and 213 μg/m^3. The minimum value corresponded to October 23rd at Lingotto, while the maximum was recorded on the 26th of October by beta-attenuation at Rebaudengo. Focusing on 26th and 27th of October, all stations recorded their maximum values with a clear trend of increase of daily concentrations compared to respective series. Data series describe coefficient of correlation ranging between 0.87 (between the betas of Lingotto and Rubino) and 0.97 (between

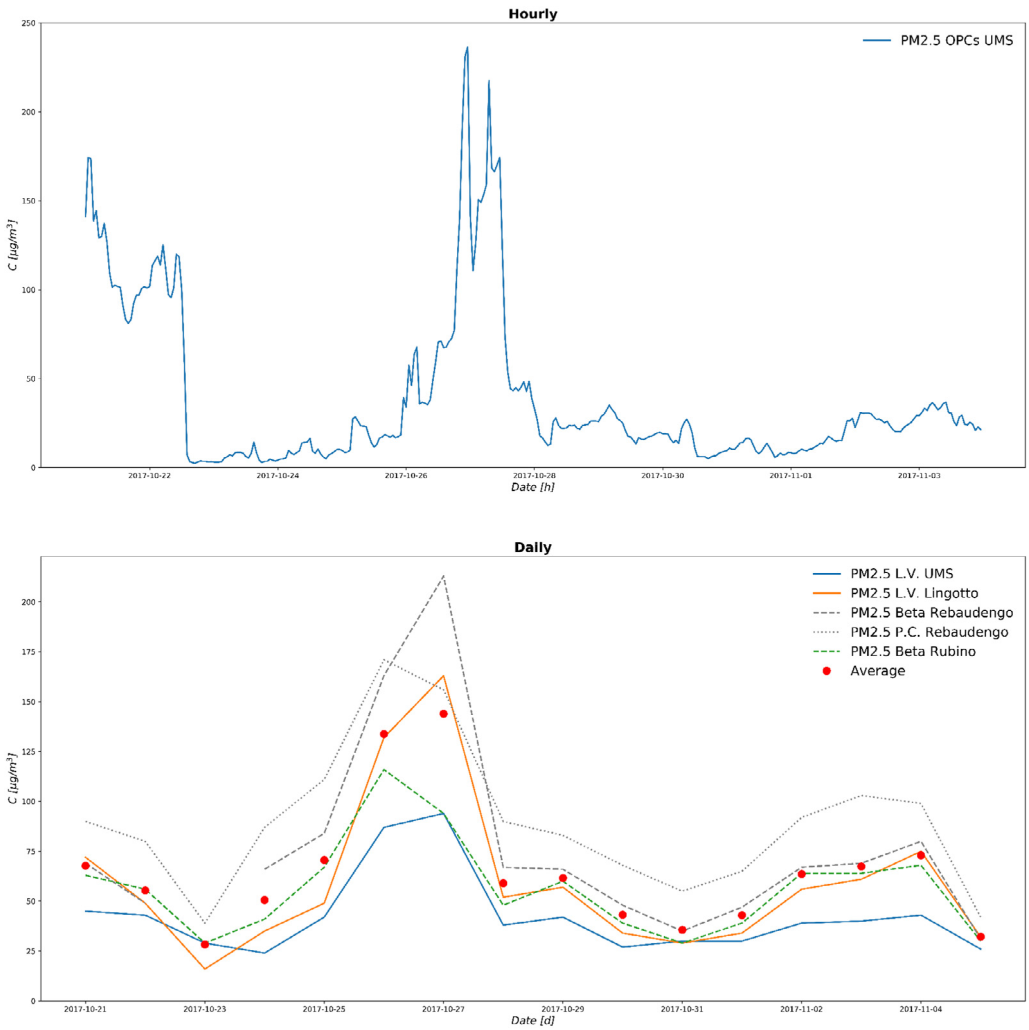

Fig. 2. Comparison of PM2.5 concentrations at UMS and ARPA's stations.

UMS and Lingotto low-volumes and between Lingotto and the beta of Rebaudengo). The occurrence in Torino of fires-related particles can also be observed by the comparison at Lingotto between daily data for the period 1st September 2017–30th November 2017 and daily averages considering the interval between 2005 and 2016 (Fig. 3).

5. Discussion

The NSMS parametrical series evidenced the highest PM_{10} value in correspondence with intense smoke and fumigation episodes of 26th and 27th of October. The following wind gusts and further evolution of fires lead both to a progressive improvement of perceived air quality and decrease of concentrations.

At UMS, both OPCs and reference instruments evidenced the urban variations of concentrations associated with the evolution of forest fires and surrounding environmental conditions (Fig. 1). Values reported at the beginning of the examined period (first 36 h) reflect the urban pollution persisting from the beginning of October under very dry and stable conditions (samples fluctuate around 50 μg/m^3).

The Foehn gusts which boosted wildfires in Susa's valley led to a significant reduction of concentrations in the city from the midday of October 22nd. For following 3 days, their scavenging effect favoured low concentration samples in the city. However, persistent emissions from local sources (i.e. domestic heating, road traffic) and progressive transfer of aerosols from the fires area, lead to an increase of urban concentrations. The OPCs describe

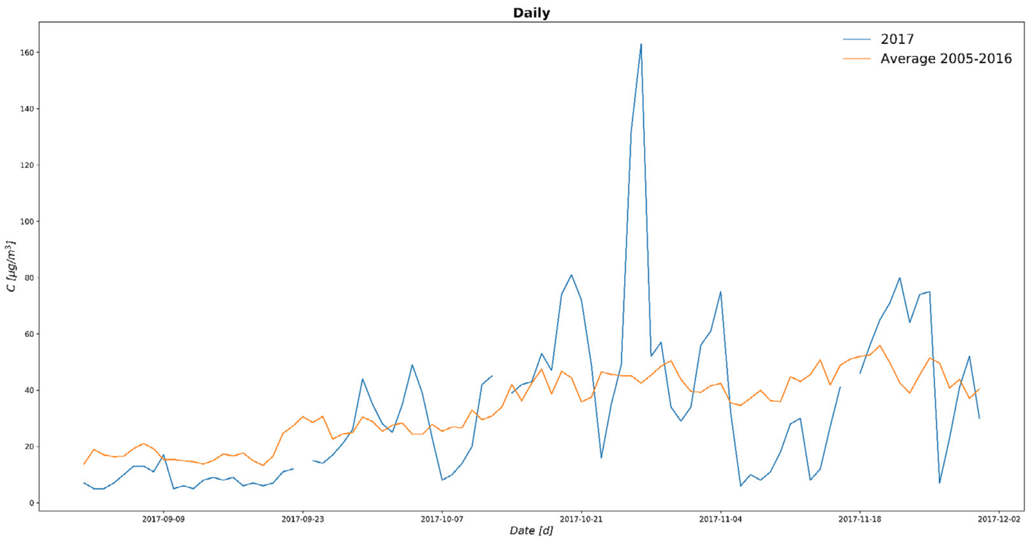

Fig. 3. Comparison between 2017 and 2005–2016 daily averages for PM2.5 at Lingotto station.

the particulate peak reaching the city from early hours of October 26th. Daily samples and the olfactory and visual perception of smoke and ash fallouts perceived in Torino in the evening of the same day and morning of October 27th confirmed this trend. The subsequent decrease in the late morning of October 27th is coherent with the reinforcement of intense Foehn gusts, which both improved air quality in Torino and boosted fires in the valleys again. From October 28th, due to the consistent intervention of firefighters and civil protection which reduced fires extension, the emergency in the city of Torino progressively subsided.

Trends between reference sampler and real-time optical instruments are coherent. However, OPCs data are influenced by their technological principle i.e. the density factor used to convert particles counting to mass concentrations. Research regarding the responses of optical and reference instruments at different conditions is currently under development by the authors.

The comparison of UMS low-volume samples with public data from ARPA's control network confirms the trend observed for the whole city of Torino (Fig. 1). Such result takes into account the indisputable differences in locations and technologies among stations. Thus, other confrontation between measurement sites is deployed.

The remarkable impact of wildfires emissions on the urban air quality is also evident in the comparison between Autumn 2017 data and the 2005–2016 averages at ARPA Lingotto station (Fig. 2). It could also be overserved the overall increase of concentrations from September to November favoured by the contribution of seasonal sources like domestic heating.

After months, the wildfires have led to some additional environmental and economic deferred relapses. In particular, focusing to Susa's valley, the loss of 24 km^2 of forests (39% of the total loss due to wildfires event) involved some areas already planned in the local wood biomass energy chain system. The intended use of such forests has supposed to cover part of the production of wood chips and pelleting which is an energetic resource of local environmental and economic interest [24]. Some of the stakeholders have responded to the loss of biomass by a partial recovering of the burned wood for energy purposes. The objective is to mitigate this huge damage in a vision of Energy Literacy [25] and avoid the direct transformation of burnt trees in wastes.

6. Conclusion

As already found in literature, the particular Italian wildfire event of 2017 confirms how climate change direct and indirect relapses could interfere locally with the dynamics of urban air quality and the biomass loss for energetic purposes. Increased summer evaporation, undergrowth desiccation and the increased frequency of long periods without rainfall is favouring the increase of occurrence and intensity of fires.

Focusing to AQ issues, the spread of such events could affect population exposures in urban areas, as observed for PM concentrations results of the case study. The development and validation over real contexts of innovative technologies to assess air quality should be treated in-depth for the improvement of our capability to manage acute events and to resolve the persisting emergency of chronic air pollution affecting entire territories such as the Po valley.

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